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Title: Risk-Assessment and Cost-Benefit Analysis Principles for Environmental Remediation Decision-Making at Department of Energy Sites

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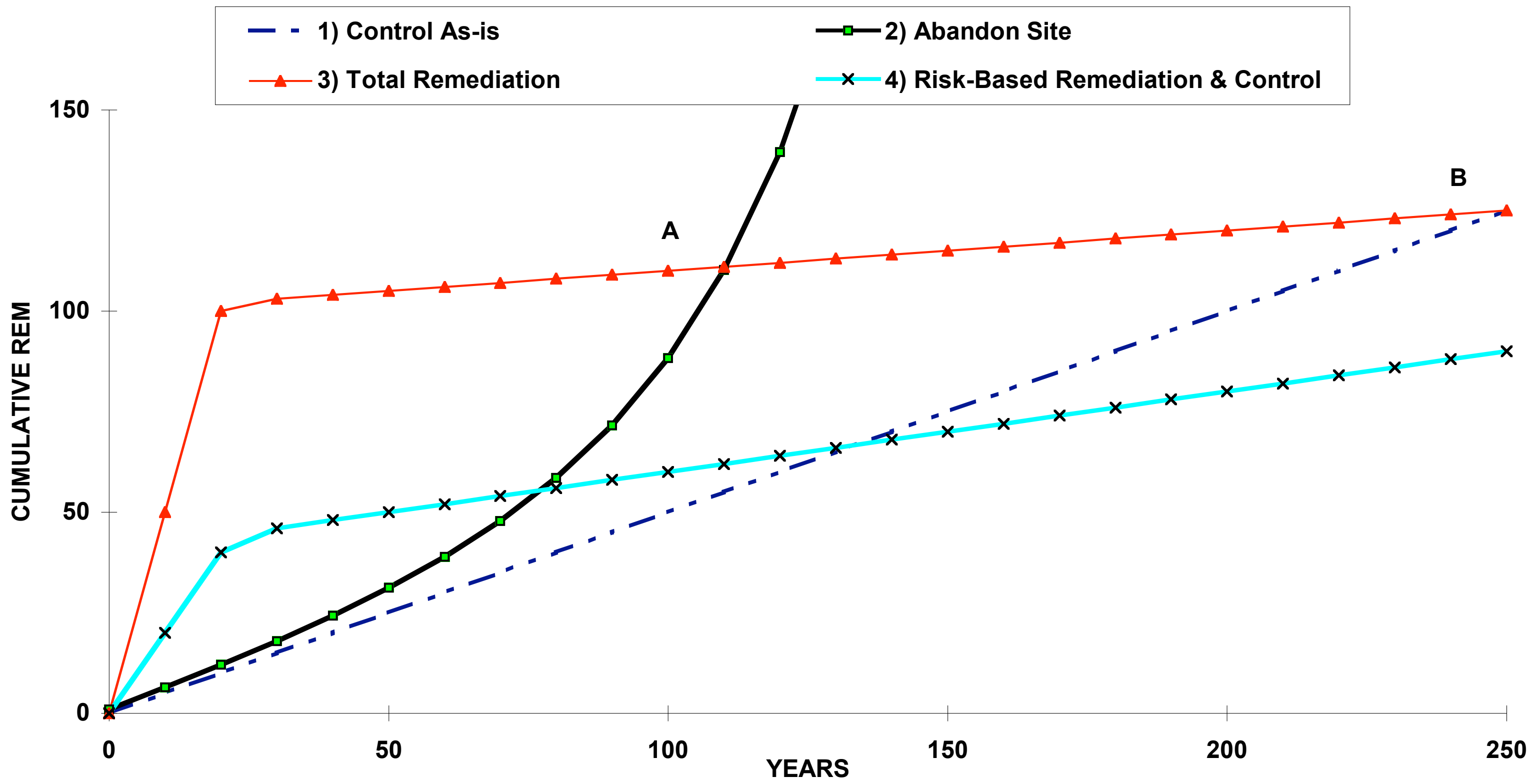
Table 1. Examples of Federal Regulatory Controls*

Regulation	Statute	Applicability	Standard	Other Applications
EPA REGULATIONS				
40 CFR 192. Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings.	UMTRCA	Cleanup criteria for uranium and thorium mill tailings and properties contaminated with uranium and thorium mill tailings.	5 pCi/g of ^{226}Ra above natural background in soil averaged over 100 m^2 to a depth of 0–15 cm. 15 pCi/g for each successive 15-cm thickness. 20 pCi/m^2//s of ^{222}Rn flux; 500-yr longevity. 20 μR/h above ambient background radiation exposure rate	Used by the DOE as the basis for part of its standards for residual radioactive material in DOE 5400.6 and has been applied under the Formerly Utilized Sites Remedial Action Program (FUSRAP). Used as an applicable or relevant and appropriate requirement (ARAR) at some NPL sites
40 CFR 141. National Interim Primary Drinking Water Regulations.	SDWA	Maximum contaminant levels (MCLS) for radionuclides in drinking water.	4 mrem/yr for beta and photon emitters. Other values for alpha-emitting radionuclides in pCi/L. Revised standards also contain guidelines for disposal of radioactive waste, Including radium, generated during the clean-up of drinking water systems	Used as an ARAR at NPL sites.
40 CFR 61. National Emission Standards for Hazardous Air Pollutants: Standards for Radionuclides.	CAA	Emission standards for eight categories of facilities.	10 mrem/yr plus other criteria, such as for radon emanation.	Used as an ARAR at NPL sites.
Proposed 40 CFR 191 (42 FR 2860; January 13, 1977). Spent Nuclear Fuel and High-Level and Transuranic Waste.	AEA	Standards applicable to the disposal of spent nuclear fuel, high-level radioactive waste, and transuranic wastes.	15 mrem/yr; 10,000-yr longevity Groundwater protection requirements.	Used as an ARAR at NPL sites for Greater-than-Class-C wastes.
40 CFR 300. National Contingency Plan (NCP) and Supporting guidance.	CERCLA	Organizational structure and procedures for preparing for and responding to discharges of oil and releases of hazardous substances, pollutants, and contaminants.	Acceptable risk range of 10^{-6} to 10^{-4}	Establishes criteria for selecting remediation goals at NPL sites.

*This table was taken from the US Environmental Protection Agency, Office of Radiation and Indoor Air, report titled "Issues Paper on Radiation Site Cleanup Regulations" (August 27, 1993).

Regulation	Statute	Applicability	Standard	Other Applications
NRC REGULATIONS				
10 CFR 20 Parts 30, 40. and 70. Standards for Protection Against Radiation.	AEA	Radiation protection criteria for NRC-licensed activities.	100 mrem/yr, plus ALARA (As Low As Reasonably Achievable)	State regulations Used as an ARAR at NPL sites
10 CFR 61. Licensing Requirements for Land Disposal of Radioactive Waste.	AEA	Procedures, criteria, and terms and conditions that apply to the issuing of licenses for the land disposal of radioactive waste produced by NRC licensees.	25 mrem/yr plus ALARA.	Used as an ARAR at NPL sites.
PRINCIPAL DOE ORDERS AND REGULATIONS				
DOE Order 5400.4. Comprehensive Environmental Response, Compensation, and Liability Act Requirements.	AEA	DOE CERCLA policies and procedures as prescribed by the NCP.	Acceptable risk range of 10^{4} to 10^{-4}	Could be used to establish remediation goals at other sites
DOE Order 5400.5. Radiation Protection of the Public and the Environment.	AEA	Standards and requirements for operations of DOE and DOE contractors with respect to protection of the public and the environment against undue risk from radiation.	100 mrem/yr plus ALARA. Also includes additional pathway and activity-specific dose limits, such as 10 mrem/yr air, 10 mrem all pathway reporting requirements, 25 mrem/yr for waste management, and others.	Could be used to set site-specific clean-up goals at other sites
DOE Order 5820.2A. Radiation Waste Management.	AEA	DOE's equivalent to NRC's 10 CFR 61 for low-level waste management includes requirements for managing 11e(2) by-product material and NARM waste. (Supplemented by DOE 5400.5).	25 mrem/yr; 10 mrem/yr for air emissions.	Could be used to set site-specific clean-up goals at other sites
Proposed 10 CFR 834 (Notice of Proposed Rulemaking, 58 FR 16268; March 25, 1993). Radiation Protection of the Public and the environment.	AEA	Proposed standards and requirements for operations of DOE and DOE contractors with respect to protection of the public and the environment against undue risk from radiation.	100 mrem/yr. plus ALARA. Also Includes additional pathway and activity-specific dose limits, such as 10 mrem/yr air, 10 mrem all pathway reporting requirements, 25 mrem/yr for waste management, and others. Best Available Technology plus ALARA for liquid waste discharges.	Could be used to set site-specific clean-up goals at other sites.

FIGURE 1 - EXAMPLE INTEGRATED RISK PROFILES



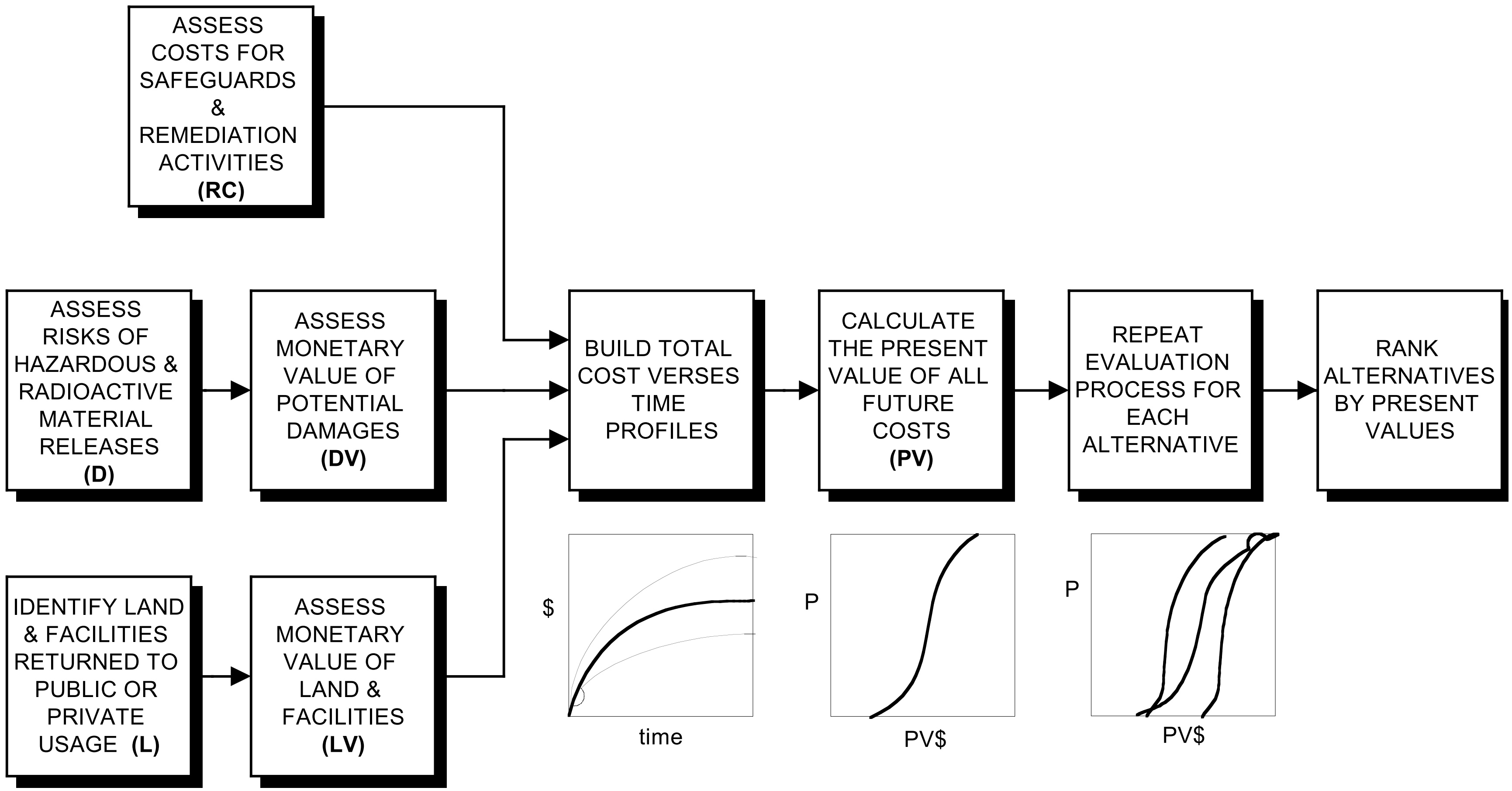


FIGURE 2
AN ECONOMIC APPROACH TO ENVIRONMENTAL REMEDIATION DECISIONMAKING

INTRODUCTION

Approximately 135 Department of Energy (DOE) sites have been identified for which the release or threatened release of hazardous and/or radioactive materials is judged to be sufficient to merit preventive and/or remedial actions to protect human health and the environment. The current process for determining the appropriate preventive and/or remedial actions is based on compliance with one or more federal regulations, including those listed in Table 1. These statutes all seek to ensure public safety by specifying material concentrations or dose levels that, for assumed exposure scenarios, result in *de minimus* human health or environmental consequences.

In many cases, it has been found that the contaminant levels required for compliance under the *de minimus* approach cannot be achieved with available technology or that, even if technically possible, will require extraordinary expenditures. For example, plans for the cleanup of US DOE sites alone are estimated to cost as much as a trillion dollars (Ref. 1). As a result of this discontinuity between regulatory requirements and real-world capability, very little actual cleanup has been accomplished.

The purpose of this analysis is to examine environmental remediation decision-making (ERD) from a cost-benefit perspective and, in the process, to advance the prospects for real and tangible economic and environmental benefits. This perspective is forged from the disciplines of probabilistic safety analysis (PSA) and programmatic risk assessment (PgRA) and economics.

OBJECTIVES OF ENVIRONMENTAL REMEDIATION

The tangible social benefits that can be derived from the remediation of DOE sites fall into three categories.

1. Reduction in the projected risks to human health and/or the environment from possible releases of hazardous and/or radioactive materials
2. The return of land and facilities to public or private use
3. Reduction of site maintenance and operations costs

Any proposed expenditures for environmental remediation should be required to provide expected benefits in these areas equal to or greater than the benefits available from commensurate investments in other government programs.

PERSPECTIVES ON RISKS, BENEFITS, AND DECISIONMAKING

In making any important decision, it is instructive to remember the old saying that in order to get the right answer, you need to ask the right question. For ERD, the decision question typically follows the process required by the National Environmental Policy Act (NEPA) and is framed as a choice between multiple remediation alternatives and a base-case “no-action” alternative. This “no-action” condition often is wrongly inferred to represent the current condition at DOE sites. In fact, even though DOE sites contain massive quantities of hazardous and/or radioactive materials, there is little if any evidence that measurable public health effects are resulting from current DOE operations. This is attributable to the active controls placed on stockpiles of hazardous and/or radioactive materials and restrictions of access to contaminated sites and facilities. The isolation of many DOE sites also makes this control process easier. Thus, there are considerable actions being taken now to maintain DOE sites in low-risk conditions. Mathematically, this can be stated in terms of the basic risk equation defining the relationship of hazard to risk (Ref. #2) as

$$RISK = \frac{HAZARD}{SAFEGUARDS} \tag{1}$$

The regulations listed in Table 1 seek to ensure that *risk* is low by eliminating the *hazards* presented at DOE sites so that *safeguards* are not necessary. However, we can see from current conditions that low risk also can be obtained through the application of safeguards.

Even in situations in which the hazard cannot be eliminated, such as for a waste repository, only naturally occurring geologic safeguards are credited for maintaining risk at a low level. The rationale for discounting the role of active safeguards in mitigating hazards generally is based on the premise that active "institutional controls" cannot be relied on over the lifetime of the hazard. Although this may be true, it is wrong to limit ERD options to "permanent" solutions that require all remedial action to be done now. The insistence on permanent solutions, in fact, may result in increased risk, depending on the planning horizon chosen. To illustrate this concern, consider the example time-integrated risk profiles shown in Fig. 1. In this example, the risk presented to the general public from radioactive materials on the site is plotted over time for four hypothetical scenarios.

1. Maintenance of the site as-is with no remediation
2. Abandonment of the site without safeguards or remediation
3. Remediation of the site to *de minimus* hazard levels
4. Risk-based partial remediation of the site with continued safeguards

For case #1, the current low risk levels a re maintained into the future, and the cumulative additional risk to the surrounding population grows slowly over time. In case #2, the risk accumulation rate increases over time as conditions on the site deteriorate without continued safeguards or remediation. For case #3, risk accumulates dramatically in the short run during the handling and processing of hazardous materials and then levels off to a new long-term, stable (but not zero) condition. Finally, in case #4, limited remediation actions and continued safeguards are combined to keep both near-term and long-term risk low. Even better risk performance could be obtained for case #4 if additional remediation actions are taken in the future.

Points A and B on Fig. 1 represent the times in the future when the cumulative risk from the permanent remediation case "breaks even" with the accumulated risk from cases #1 and #2. If a remediation option that provides for break-even within a reasonable time frame cannot be identified, then there is not a compelling case for proceeding with remediation to reduce risk. There is strong *prima facie* evidence that this is the situation for many DOE sites when remediation options are compared with actual current conditions rather than the abandonment case. As a result, remediation then must be justified through objectives #2 and #3 discussed above.

Therefore, the question that should be answered by the ERD process is not; "How can the hazard best be eliminated?" But; "How can risk most efficiently be managed?"

PROPOSED APPROACH

Economics can be defined as the study of how people make decisions between competing alternatives when faced with scarce resources. If we view ERD from an economic perspective, then possible environmental remediation options for a specific site represent different possible cost streams extending into the future. The components of the future cost streams may represent expenditures for remediation and safeguards activities, the economic value of damage caused by the presence of hazardous and/or radioactive materials in the environment, or the assessed value of lands and facilities returned to public or private usage.

As indicated earlier, the ERD evaluation typically will include multiple alternatives developed for comparison with a base-case, no-action alternative. The site remediation decision then consists of choosing a single action path from multiple, mutually exclusive alternatives. In evaluating this type of multiple-alternative decision in which only one alternative can be exercised, a comparison of the present value of all future costs and benefits should be used. Although the benefit-cost ratio (B/C) comparison method also can be used to identify the optimum economic choice, the analysis must be done in a sequential, pair-wise manner (Ref. 2). Because the proper usage of the B/C method in this application is poorly understood and often performed incorrectly, the more straightforward approach of calculating the present value of all future costs (and benefits) is recommended. Economic efficiency then is maximized by choosing the remediation option with the lowest present value of future costs. Because our knowledge of the parameters of this analysis is imperfect, it must be performed probabilistically with a systematic and comprehensive treatment of uncertainty in all data and results. The major steps involved in this process are presented in Fig. 2. Mathematically, the steps shown on Fig. 2 can be expressed as:

$$PV = \int_0^T \sum \left[(RC + DV - LV) / (1 + IR)^T \right] dt \quad , \tag{2}$$

where

PV = present value,
RC = remediation costs,
DV = the monetary value of damages caused by the presence of hazardous and/or radioactive materials in the environment,
LV = the monetary value of lands and facilities returned to public or private use as the result of remediation actions,
IR = the real interest rate used to discount future monetary costs and benefits, and
T = the time between now and the incidence of costs or benefits in years.

If the differences in estimated risks between the alternatives can be demonstrated to be small, similar to the Fig. 1 example, then the damage value term (DV) can be neglected.

OBJECTIONS TO ECONOMIC ANALYSIS

The application of a rational, economic approach to ERD is not a new idea. Approaches like the one shown in Fig. 2 are generally dismissed by environmental advocates using arguments such as the following.

- The monetary value of measurable health and environmental consequences cannot be agreed on by all stakeholders.
- Some ecological benefits cannot be given a monetary value.
- Economic analyses fail to incorporate issues of social welfare and environmental justice.
- Uncertainties in risk assessment calculations are to too great to provide a reliable decision basis.

The general rebuttal to these concerns is straightforward. Insufficient resources exist to reduce all risks to *de minimus* levels and satisfy all other stakeholder concerns. Choices must be made between environmental benefits and costs. The defaulting of ERD to political resolution only ensures that more resources will be consumed in unproductive bureaucratic processes and less in actual environmental protection and improvement. Specific responses to the above concerns are also apparent.

1. As discussed previously, proper definition of the alternatives may show that risk is not a key decision variable, eliminating the need to establish a monetary value for risk.
2. When desired, monetary values for avoided risks can be quantified and included in Equation (2). When remediation decisions are made (or not made), the possible health and environmental damages that may result (or be avoided) are valued implicitly, including externalities. Thus, by examining decisions that have been made, the inferred value of environmental benefits can be quantified. Values derived from actual cases then can be applied to examine other as yet unresolved remediation decisions. This inferred monetary valuation of possible damages would be used in the second step of the valuation process shown in Fig. 2. The first step, the assessment of the magnitude of possible health and environmental damage, still can be examined with site-specific models and data.
3. To the extent possible, social welfare and environmental justice concerns should be incorporated into the economic analysis. For example, the concern that land value differentials between contaminated and uncontaminated areas left open for residential usage may result in poor communities being subject to disproportionately high environmental risks can be addressed directly by assessing the costs of compensating measures such as zoning restrictions or governmental land repurchases. Environmental equity is another issue that typically thwarts decision making. Even under the safest conditions, no community wants to be the one stuck with society's "garbage," but it has to go somewhere. For this type of issue, it is reasonable to include monetary compensation for the affected community in Equation (2).
4. Some social welfare and environmental justice issues, such as "peace of mind" will remain as externalities. These remaining externalities can and should be included in the decision-making process. A general approach for their inclusion is to allow alternatives initially ranked through a comprehensive monetary analysis to be re-ranked based on subjective assessments of social welfare or other issues. This two-step process ensures that the price effectively being paid for the achievement of social welfare goals is made explicit. ERD should never be

based solely an abstract multi-attribute point system where the implicit monetary value of issues such as social welfare and environmental justice can be obscured intentionally.

5. The "uncertainty is too large" argument is an old one and the most fallacious of all. The more significant the uncertainty, the more critical it is that it be acknowledged and quantified. The record is replete with real-world examples where pretending that uncertainty does not exist or hiding it under indefensible assumptions has led to disaster in decision-making. Mature tools and techniques are available from PSA to comprehensively quantify uncertainty in ERD, identify its sources, and develop strategies for minimizing risk.

CONCLUSION

ERD is too often confined by the current hazard-based regulatory system to a choice between site abandonment and permanent, one-time cleanup. This restrictive "black and white" system reduces public discussion to alternatives that are either unacceptable or unachievable. As a result, the current ERD process is characterized by inaction. This paper outlines an approach to ERD that allows the consideration of other remediation scenarios that rely on the continued management of risk to provide adequate safety. After broadening the choices available for remediation and placing risk in proper perspective, economic analysis can be used to direct the decision process and yield remediation plans that produce lower risk ***and*** lower cost than current methods.

REFERENCES

1. "Losing the Nuclear Waste War," Los Angeles Times (November 27, 1994), p. A-1.

2. S. Kaplan and B. J. Garrick, "On the Quantitative Definition of Risk," *Risk Analysis* (1981).

3. E. L. Grant, W. G. Ireson, and R. S. Leavenworth, *Principles of Engineering Economy*, Sixth Edition (The Ronald Press, New York, 1976).